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Effectiveness of interventions to reduce household air pollution from solid biomass fuels and improve maternal and child health outcomes in low- and middle-income countries

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- 1 Effectiveness of interventions to reduce household air pollution from solid biomass fuels
- 2 and improve maternal and child health outcomes in low and middle-income countries; a
- 3 systematic review and meta-analysis
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43 Abstract

61

Interventions to reduce Household Air Pollution (HAP) are key to reducing associated 44 morbidity and mortality in low- and middle- income countries (LMICs); especially among 45 46 pregnant women and young children. This systematic review aims to determine the effectiveness of interventions aimed to reduce HAP exposure associated with domestic solid 47 biomass fuel combustion, compared to usual cooking practices, for improving health 48 outcomes in pregnant women and children under five in LMIC settings. 49 A systematic review and meta-analysis was undertaken with searches undertaken in 50 51 MEDLINE, EMBASE, CENTRAL, GIM, ClinicalTrials.gov and Greenfile in August 2020. Inclusion criteria were experimental, non-experimental or quasi-experimental studies 52 investigating the impact of interventions to reduce HAP exposure and improve associated 53 health outcomes among pregnant women or children under five years. Study selection, data 54 extraction, and quality assessment using the Effective Public Health Practice Project tool, 55 were undertaken independently by two reviewers. 56 17 out of 7293 retrieved articles (seven pregnancy, nine child health outcome; 13 studies) met 57 the inclusion criteria. These assessed improved cookstoves (ICS) (n=10 studies), ethanol 58 59 stoves (n=1 study) and Liquefied Petroleum Gas (LPG) (n=2 studies) stoves interventions. Meta-analysis showed no significant effect of ICS interventions compared to traditional 60

ivieta-analysis showed no significant effect of ites interventions compared to traditional

cooking for risk of preterm birth (n=2 studies), small for gestational age (n=2 studies) and

62 incidence of acute respiratory infections (n=6 studies). Although, an observed increase in

63 mean birthweight was observed, this was not statistically significant (n=4). However, ICS

64 interventions reduced the incidence of childhood burns (n=3; observations = 41,723; Rate

65 Ratio:0.66 [95% CI: 0.45-0.96]; I²:46.7%) and risk of low birth weight (LBW) (n=4;

66 observations = 3456; Odds Ratio:0.73 [95% CI: 0.61-0.87]; I²: 21.1%).

| 67 | Although few studies reported health outcomes, the data indicate that ICS interventions were |
|----|---|
| 68 | associated with reduced risk of childhood burns and LBW. The data highlight the need for the |
| 69 | development and implementation of robust, well-reported and monitored, community-driven |
| 70 | intervention trials with longer-term participant follow-up. |
| 71 | Key words: Environmental health; intervention effectiveness; indoor air pollution, pregnancy |
| 72 | outcomes, child health outcomes; health improvement. |
| 73 | Systematic review registration: Protocol identifier: <u>https://doi.org/10.1186/s13643-021-</u> |
| 74 | <u>01590-z</u> . PROSPERO ID: CRD42020164998. |
| 75 | Practical implications: |
| 76 | • A number of health benefits are identified by using an improved cookstove (ICS) |
| 77 | including reduced risk of low-birth weight, burns, and acute lower respiratory |
| 78 | infections within high altitude settings. |
| 79 | • Considering uptake and compliance of the intervention, alongside the health benefits, |
| 80 | provides contextual relevance for interpretation of findings of both the included |
| 81 | studies and this systematic review. |
| 82 | • Future intervention studies should actively consider in their study design i) Improving |
| 83 | standardisation of outcome definitions, timing of intervention deployment and |
| 84 | duration of follow-up to outcome assessment, ii.) Taking more detailed measurements |
| 85 | and clear reporting of intervention compliance, iii.) Providing an assessment of the |
| 86 | potential of short-medium term interventions. |
| 87 | • Adopting and taking into consideration these recommendations would inform research |
| 88 | priorities and enable robust policy formation for delivery of HAP interventions. |
| | |

89 1. Introduction

106

90 Complex interventions such as those to reduce household air pollution (HAP) which include several multiple interacting components, are challenging to evaluate due to practical and 91 92 methodological difficulties. However, evaluation is necessary to assess important health consequences and improve population health.¹ HAP is produced from the burning of biomass 93 (wood, dung charcoal and crop residue), coal and kerosene for cooking, heating and lighting 94 in typically poorly ventilated settings, generating hazardous levels of carbon monoxide (CO), 95 particulate matter (PM), nitrogen dioxide (NO₂) and sulphur dioxide (SO₂).² 96 Interventions to reduce HAP exposure include introduction of cleaner fuels (e.g., Liquefied 97 Petroleum Gas (LPG), ethanol, electricity, solar stoves, biogas, natural gas)³ which could 98 reduce levels to below the World Health Organization's Indoor Air Quality (WHO-IAQ) 99 100 guidelines if fully adopted. At a clean energy transition stage fuel 'stacking', or incomplete uptake may occur, whereby users continue to use traditional cooking methods and fuels 101 alongside cleaner sources; thereby reducing efficacy of the intervention.⁴ Populations in low 102 103 and middle-income countries (LMICs) often face multiple barriers to adoption of HAP interventions, including accessibility, affordability, lack of sustainable infrastructure and 104 interventions not meeting cultural and social preferences. This is particularly the case with 105

107 Indoor Air Quality Guidelines (2014) focus particular attention upon reducing pollutants as

long-term interventions that require significant transition and behavioural adaptation. WHO

108 much as possible – by clean fuel transition - given the need to reduce PM2.5 exposure to low

109 levels to generate health benefits⁵; recommendations which have been reiterated in the

updated global air quality guidelines (2021).⁶ However, the guidelines also provide evidence-

111 based recommendations for policies to be enacted within the clean fuel transition period

112 (including introduction of Improved Cookstoves), recognising that intermediate steps will be

113 necessary in many low-income settings. These include measures such as improved

cookstoves (ICS);⁷ improved biomass fuels (e.g., briquettes, biomass pellets)⁸ and behavioural
changes (e.g., ventilation, outdoor cooking)⁷ to address the global burden of arising disease
from HAP.⁹ However, these often fail to achieve substantive reduction in HAP levels
sufficient to prevent health harms and improvements may not meet WHO-IAQ Interim
Targets.⁷

Interventions are needed to reduce the health, socio-economic and environmental
consequences associated with HAP, which disproportionately affect pregnant women and
young children.¹⁰ In pregnancy, causally associated health outcomes with HAPs¹¹ include
gestational hypertension, intrauterine growth retardation (IUGR) preterm birth, stillbirth,
birthweight, and perinatal mortality.¹² In children aged under five years investigated health
outcomes include acute lower respiratory infection (ALRI), asthma, otitis media, impaired
neurodevelopment and mortality in early life.^{13,14}

Previous systematic reviews have focused on the effect of interventions upon HAP 126 concentrations or exposure levels¹⁵ or have selected specific interventions (e.g., ICS)^{7,16} or 127 health outcomes,^{17,18} without assessing the benefit of intervention options upon maternal and 128 child health. Systematic reviews on uptake and sustained use of both ICS and adoption of 129 cleaner fuels¹⁹ have been undertaken, highlighting contextual and compositional factors that 130 should be considered when planning and implementing such interventions. This systematic 131 review aims to provide an evidence synthesis for the overall benefit of HAP interventions, 132 compared to usual practice from experimental and non-experimental studies, on maternal and 133 child health outcomes in pregnant women and children under five in LMIC settings. Sustained 134 uptake of these HAP interventions is also discussed. 135

136 2. Methods

A detailed protocol for the systematic review and meta-analysis has been published
previously²⁰ and registered on PROSPERO (ID: CRD42020164998).²¹ The focus of this
review is any domestic intervention aiming to reduce HAP exposure associated with cooking,
heating and lighting and the associated effect upon pregnancy and under five child health
outcomes, among those living in LMICs.

142

2.1. Search strategy and selection

In August 2020 MEDLINE (in process and 1947 – present); EMBASE (1947 – present); 143 CENTRAL; The Global Index Medicus (GIM) (WHO, 2020a); ClinicalTrials.gov and 144 GreenFILE ²³ were searched using index and free text terms for "Population" AND 145 ("Intervention" OR ("Household Air Pollution" AND "LMICs") (MEDLINE search strategy 146 in Appendix 1). Reference lists of included studies, and relevant systematic reviews identified 147 by searching Epistemonikos,²⁴ were viewed to capture any additional studies. The WHO 148 International Clinical Trials Registry Platform (ICTRP)²⁵ was searched later in September 149 150 2020 due to earlier closure of the portal for Covid-19 research only. Article screening (by title 151 and abstract) and full paper selection were undertaken independently by two reviewers (HL, JS, KEW or EDC), with differences in article selection discussed and resolved as a group. 152

153 **2.2.** Eligibility criteria

Study eligibility was determined using Population-Intervention-Comparator-Outcome-Study design (PICOS) criteria (Table 1). The study population was defined as pregnant women and/or children under five years, residing in LMICs, as defined by the OECD Development Assistance Committee (DAC) list²⁶ at the time the studies were completed, who are exposed to HAP produced from cooking, heating and lighting with solid biomass fuels. Interventions (i.e., cleaner fuels, structural (e.g., improved cookstoves, chimneys), behavioural) had to target solid biomass cooking, heating or lighting to reduce HAP, which was compared to 161 control groups (i.e., usual practices) or an alternative intervention (i.e., any other intervention162 within the inclusion criteria).

Studies had to report at least one health outcome related to the pregnancy/perinatal period 163 164 (within one week of birth) (e.g., IUGR, birthweight, low birth weight, preterm birth, preeclampsia, blood pressure, gestational diabetes, maternal mortality, perinatal/infant mortality, 165 stillbirth and miscarriage) or in children under five years (e.g., upper and lower respiratory 166 tract infections, pneumonia, asthma, respiratory distress syndrome, otitis media, impaired 167 neurodevelopment, mortality and burns), previously associated with HAP. Eligible study 168 designs were randomised control trials (RCTs), non-randomised control trials and quasi-169 170 experimental or natural experimental studies (including before-after studies and interrupted time-series studies, if pre-and post-intervention health outcomes were recorded). 171

There was no exclusion by publication date, language or type of publication, with exclusiononly occurring when all five areas of the PICOS inclusion criteria were not met.

174 **2.3. Data extraction**

175 Data extraction of included studies was undertaken independently by two reviewers (HL, JS or KEW) and any disagreements were discussed and if necessary adjudicated (by EDC). Data 176 177 extraction used an adapted (to study design) Cochrane Public Health Group data extraction form, collecting information on study characteristics (i.e., population, geographical setting, 178 179 inclusion and exclusion criteria), health outcomes (i.e., type of outcome, definitions, scales and time points measured) and interventions details (i.e., type of intervention and 180 comparators, uptake and adoption, air pollution measurement details). Authors were contacted 181 182 if further clarification or information was required.

183 **2.4. Risk of Bias**

Quality and risk of bias was assessed using the Effective Public Health Practice Project;²⁷
independently by two reviewers (HL, JS or KEW), adjudicated by EDC; at a study level
based on the primary outcome. The quality and bias assessment was reported for six
components (selection bias, study design, confounders, blinding, data collection methods,
withdrawals and dropouts). It was accepted that blinding and random allocation of
participants may not have been fully possible, given the nature of the interventions and
settings.

191 **2.5. Evidence synthesis**

Narrative synthesis was undertaken for each unique population-intervention-outcome triad 192 and for intervention compliance, defined as the uptake and sustained use of the intervention. 193 Meta-analyses, were undertaken in STATA Version 16.1²⁸. A random effects model was 194 195 applied due to the environmental and methodological variation between studies contributing to each analysis; for example differences between specific types of cook stove (intervention) 196 197 or biomass composition (comparator). The Sidik and Jonkman method was used due to the 198 low number of studies included in each meta-analysis as it reflects uncertainty in the estimation of between-study heterogeneity through widening the confidence interval.^{29–31} For 199 comparisons, continuous data were reported as mean differences and standard deviations, 200 201 dichotomous data as odds ratios (95% confidence interval (CI)) and rate ratios (95% CI). In each meta-analysis, variability in effect estimates between studies beyond that expected by 202 chance alone was quantified with the l^2 statistic. The Chi² test for heterogeneity and the 203 between study-variance (Tau²) were also computed. Where I^2 indicated substantial 204 heterogeneity²⁹ further sub-analysis was undertaken by geographic region (e.g., Africa, Asia 205 etc.) as defined by the United Nations.³² Additionally, an exploratory analysis was undertaken 206 for birthweight and LBW, due to the discovery of a variation in timing of deployment of the 207

208 intervention within pregnancy. Funnel plots and a test for small study effects were not

209 undertaken due to the small number of studies in each meta-analysis.^{29,33}

210 **3. Results**

The searches identified 10367 records (before duplicate removal) (Figure 1), with 17 articles (reporting on 13 studies) being eligible for inclusion after screening and full paper review; six studies reported pregnancy outcomes^{34–40} and nine studies reported child health outcomes.^{41–49} Three studies were reported across two articles each: RESPIRE,^{39,48} Nepal step-wedge ICS and LPG intervention^{38,49} and ethanol cookstove^{35,50} (Appendix 2).

216

3.1. Study characteristics

Of the six studies (seven articles) investigating a range of pregnancy outcomes (Table 2), all were RCTs and stove-based interventions (Figure 2) (e.g., ICS=3, ethanol stove=1 and LPG and ICS=2). Study quality was found to be strong (n=3), moderate (n=1) and weak (n=2) with studies being classified as weak where a lack of detail prevented a confident assessment of quality.

All of the nine (nine articles) child health outcome studies, comprising eight RCTs^{41,43–49} and one interrupted time series,⁴² investigated ICS interventions; with one study having both an ICS and an improved fuel (briquettes).⁴⁵ Study quality was found to be strong (n=6), moderate (n=2) and weak (n=1) respectively, with moderate or weak study quality designated due to the study design and outcome measurements.

- 227 Household air pollution measurements were reported in 10 studies, with a reduction in
- pollutant levels observed in four ICS interventions,^{39,41,45,47,48} and two ICS/LPG
- interventions;^{38,51} none of which were below the WHO-IAQ guidelines.
- 230 **3.2.** Pregnancy outcomes

231

3.2.1. ICS interventions vs traditional cooking

232 3.2.1.1. Birthweight

Four studies undertaken in India,³⁷ Nepal,³⁸ Ghana⁴⁰ and Guatemala,³⁹ compared ICS to 233 234 traditional stove cooking, with variation in deployment date of the ICS ranging from before conception to final stage of pregnancy (Table 2). Timing of birthweight measurement varied 235 between studies, recorded within 24 hours⁴⁰ (n=1), 48 hours³⁹ (n=1) and 72 hours³⁸ (n=1) of 236 birth, or by maternal self-report.³⁷ The meta-analysis showed a higher absolute mean 237 birthweight of 25.94 g (95% CI: -16.18 - 68.05) (figure 3) in ICS compared to traditional 238 stove cooking, but the wide confidence interval for birthweight meant the association was 239 240 insignificant. An exploratory sub-analysis restricted to those studies (n=3) in which the ICS was deployed within the third trimester of pregnancy only, gave a similar result (25.99 g; 95%) 241 CI: -24.01 - 78.99) (Appendix 3). 242

243

3.2.1.2. Low Birth Weight (LBW)

Three of the four studies which investigated birthweight also reported prevalence of LBW 244 (Nepal,³⁸ Ghana⁴⁰ and Guatemala³⁹), in addition to a study investigating only LBW in rural 245 Bangladesh;³⁴ which deployed the ICS intervention within the first trimester and recorded 246 birthweight within 72 hours of delivery. All studies except for one³⁴ (which provided no 247 relevant definition), categorised LBW as a birthweight of <2500 g. Only one study 248 (Bangladesh)³⁴ observed a decrease in the odds of LBW associated with an ICS intervention 249 compared to traditional cooking (Table 3). In Nepal³⁸ there was no observed change in odds 250 of LBW with the timing of intervention deployment by stage of pregnancy, after adjusting for 251 confounders. In the meta-analysis, there was an observed decrease in the odds of LBW in the 252 intervention compared to control groups (OR: 0.73; 95% CI: 0.61 - 0.87) (Figure 4). Two 253 additional sub-analyses were undertaken (Appendix 4 and 5), showing similar results when 254

the intervention was deployed in the first trimester (OR: 0.73; 95% CI: 0.54 - 0.97) in the
intervention compared to the control group. However, when the ICS was deployed in the third
trimester there was no evidence of an effect in the odds of LBW between the intervention and
control arms (OR: 1.04; 95% CI: 0.73 - 1.47).

2593.2.1.3.Preterm birth (PTB) and Small for Gestational Age (SGA)

Only two studies, in Nepal³⁸ and Ghana⁴⁰ investigated the effect of ICS on risk of preterm
birth and SGA, with one³⁸ defining preterm birth as delivery before 37 weeks; in the other no
definitions could be ascertained.⁴⁰ In the meta-analysis (figure 5 and 6) no clear evidence of a
decrease in the odds of PTB or SGA with the intervention was observed (OR: 0.89; 95% CI:
0.67 - 1.17; OR: 1.02; 95% CI: 0.86 - 1.20, respectively).

265 3.2.2. Ethanol fuel interventions

A large trial was undertaken in Nigeria which investigated the effect of an ethanol cookstove 266 intervention deployed at 18 weeks gestation compared to firewood, reporting multiple 267 pregnancy outcomes⁵⁰ and blood pressure during pregnancy.³⁵ Some health improvements 268 were identified (Table 3), including an increase in birthweight (Adjusted mean difference: 197 269 g; 95% CI: 25 - 368), and an increase in gestational age at delivery (Adjusted mean 270 271 difference: 1.6 weeks; 95% CI: 0.04 - 3.2). No significant exposure-response relationships were observed. Additionally, no significant decrease in diastolic blood pressure during 272 273 pregnancy was observed in the ethanol group compared to the firewood group. However, all controls were given information regarding the health harms of cooking smoke and details on 274 how to reduce their exposure (e.g., cooking in a well ventilated room or cooking outside), 275 reducing the ability to observe the true effect of the full intervention. In addition, the study 276 was powered to detect an effect size difference between control and intervention groups for 277

birthweight and preterm birth only, with many of the outcomes being underpowered, alongwith a low number of users in the firewood group.

280 3.2.3. LPG stove interventions

Two LPG stove interventions were investigated, one comparing LPG stoves deployed at 28 281 weeks gestation to traditional cooking in rural Ghana⁴⁰ and the second comparing LPG stoves 282 to ICS both deployed prior to conception in rural Nepal.³⁸ Both studies showed no statistical 283 significant improvement in pregnancy outcomes (birthweight, LBW, PTB, gestational age, 284 SGA and stillbirth); however, in Nepal there was only a 50% compliance with the 285 intervention measure. Blood pressure was also investigated in a subsample of the Ghana 286 Randomized Air Pollution and Health Study (GRAPHs),⁵¹ showing no statistically significant 287 reduction in blood pressure in the intervention (combined LPG stoves or ICS) group 288 289 compared to the traditional cooking group. However, a significant exposure-response relationship with CO was observed. Due to the differences in control group characteristics and 290 291 variation in the timing of intervention deployment between these two studies a meta-analysis 292 was not performed.

293

3.3. Child Health outcomes – Improved Cookstoves

3.3.1. Acute Respiratory Infection and Acute Lower Respiratory Infection

Of the nine studies reporting ARI and ALRI, in Ethiopia,⁴¹ Guatemala,^{42,48} Peru,⁴³ Rwanda,⁴⁴ Gambia,⁴⁵ Malawi,⁴⁶ Mexico,⁴⁷ and Nepal,⁴⁹ one used swabbing to detect pneumococcal nasopharyngeal carriage at a single time point as a proxy for ARI,⁴⁵ three used a non-specific definition^{42,47,49} and five used the WHO Integrated Management of Childhood Illnesses (IMCI) definition of pneumonia and severe pneumonia.^{41,43,44,46,48} ARI and ALRI were assessed by trained nurses (n=5), a fieldworker (n=1), maternal reports (n=1), nasopharyngeal swabs samples (n=1) and both maternal reports and fieldwork assessment (n=1). One study⁴⁶

also reported asthma and death as adverse events and another⁴⁹ reported a decrease in 302 persistent cough and wheeze; however, there was no evidence for a reduction in fever, severe 303 ALRI or ear discharge (actual result not reported). Only one study⁴⁸ observed a significant 304 decrease in fieldworker assessed ARI risk (risk ratio 0.56; 95% CI:0.32-0.97) and a 305 significant exposure-response relationship (RR: 0.82; 95% CI: 0.70-0.98). Three studies were 306 excluded from the meta-analysis as the articles only reported effect estimates^{47,49} or did not 307 report a rate/count of the number of events;⁴⁵ in addition one study only reported ARI.⁴¹ In the 308 meta-analysis, ARI (figure 7) was observed to decrease in the intervention group (RR: 0.94; 309 95% CI: 0.88-1.01); however there was a substantial level of heterogeneity observed (I^2 59.4; 310 p < 0.13]). The level of heterogeneity was also high in the ALRI meta-analysis (figure 8) (I^2 311 80.4%; p<0.01]); with overall it being unclear whether there is a decrease in the rate of ALRI 312 in the intervention compared to the control group (RR: 0.75; 95% CI: 0.55 - 1.03); with the 313 confidence interval including both the null and a substantial benefit. In the stratification by 314 geographic region, studies undertaken in Latin America, which were both located at high 315 geographic elevation, displayed a decrease in the risk of ALRI in the intervention compared 316 to control (RR: 0.70; 95% CI: 0.53-0.93). However, this effect was not seen in studies 317 undertaken in Africa (RR: 1.01; 95% CI: 0.59 - 1.73), where a considerable level of 318 heterogeneity remained (I^2 76%). 319

320 3.3.2. Burns

Cooking-related burns among children were reported as secondary or adverse health outcomes in three studies (Ethiopia,⁴¹ Rwanda,⁴⁴ Malawi⁴⁶); however, only one study⁴⁴ provided a definition of maternal-reported burns in their child occurring in the two months before the fieldworker visit. Of the three studies, only one study⁴⁴ showed clear statistical evidence of a decrease in the frequency of burns in the intervention group, at an individual study level. In the meta-analysis (figure 9) cooking using an ICS was observed to decrease the
risk of burns (RR: 0.66; 95% CI: 0.45-0.96) compared to the control group.

328

3.4. Assessment of Intervention Compliance

Difference in the measurement and reporting of intervention compliance was observed 329 between all included studies, looking at stove use,^{37,41,43–45,48} functioning of stove^{39,41,44,48} and 330 sole use of new fuel⁴⁵ (Appendix 6). Of the 13 included studies four did not report compliance 331 ^{34–36,42,47}, one study obtained self-reported measures of compliance,³⁷ four studies used both 332 self-report and fieldworker observations,^{41,43–45} three studies used fieldwork observations^{38–} 333 ^{40,48,49,51} and a single study used objective stove-use monitors.⁴⁶ Only six out of the nine 334 studies measured compliance, and those reported the level of compliance to range from 41 -335 90% for use of the intervention stove, with one study⁴⁴ reporting reducing compliance across 336 337 the trial period.

338 4. Discussion

339 This systematic review identified 13 eligible studies exploring the impact of HAP intervention measures (which presented seven pregnancy and nine child health outcomes), undertaken in a 340 variety of LMIC settings, with a range of follow-up times and health outcomes. All 341 342 interventions included were structural (e.g., improved cookstoves, chimneys) or clean fuel transitional interventions aimed at harm mitigation; often with complex designs (e.g., 343 344 continuous intervention deployment) of multiple interventions and reported health outcomes. There was a range of study methodological quality with the weakest studies being hampered 345 by poor reporting; in addition to differing outcome definitions, measurement timings in 346 relation to health events, intervention deployment and assessment of compliance. In addition, 347 this systematic review goes beyond that on the Thakur et al.⁵² review including three large 348 scale peer reviewed papers providing 1,271 observations for pregnancy outcomes and 25,195 349

child observations, a broader geographical scope, addition of grey literature and inclusion ofchildhood burns as a health outcome.

Within this systematic review, evidence synthesis suggests that the use of ICS results in a 352 353 reduction in risk of LBW, burns and ALRI among children aged under five years in high altitude wood cooking settings in Latin America. However, these results could be due to 354 differing situational factors of high altitudes compared to lower altitudes, for example lower 355 temperatures and reduced ventilation⁵³ as well as differences in respiratory physiology.⁵⁴ 356 Misclassification of health outcomes is also likely to have been further compounded by the 357 timing of the intervention in relation to the disease progression, reducing the potential 358 observed effect. In addition, exposure-response relationships indicates that PM2.5 needs to be 359 reduced to low levels to reduce ALRI risk;⁵⁵ as reflected by the WHO-IAQ. It is also 360 recognised that any reduction in PM2.5 due to HAP exposure is of wider benefit for child 361 health. Further randomised controlled trials to assess effectiveness for improving pregnancy 362 outcomes should deploy the selected intervention prior to or early in the first trimester, as this 363 364 reflects the period in which the foetus is most vulnerable to adverse impacts of air pollution exposure;^{56–58} supported by our finding that deployment in the first trimester may reduce risk 365 of LBW.^{34,38} In addition, the greater mean birthweight observed with use of ICS compared to 366 367 controls, could have clinical significance even though no statistical significance was observed; corroborated with substantive body of observational evidence documenting the 368 health benefits of cleaner cooking. In addition, to improvements in pregnancy outcomes being 369 seen within modest reduction in CO exposure.⁵⁹ Biological plausibility between HAPs and 370 pregnancy or child respiratory outcomes has been well documented.¹² Carbon monoxide 371 372 exposure and reduction in maternal lung function, results in oxidative stress, reducing oxygen availably to the foetus.¹² However, there is less understanding of the role of PM, but PM can 373 reduce maternal lung function and cause inflammation.⁶⁰ Conversely, PM reaches deep inside 374

the immature lungs of children causing inflammation, oxidative stress and reduces lung
development.⁶¹ HAPs do not directly cause burns but instead the stove safety is the
mechanism for reducing harm. However, for the other included health outcomes it is difficult
to draw any substantive conclusions as to the health benefit of the respective interventions due
to variations in setting, contextual characteristics, outcome assessment. timing of intervention
deployment, intervention follow up, study quality and sample size; which is consistent with
previous evaluation of HAP interventions with regard to other outcomes.^{7,16,62}

Duration of follow-up is an important additional consideration to timing of intervention 382 deployment. The unresolved heterogeneity within the ALRI meta-analysis, which could not 383 be explained by differences in study setting or design, was driven by the study undertaken by 384 Mortimer et al. 2017;⁴⁶ who recruited children up until six months before the end of the study, 385 resulting in an internal variation in follow-up duration. At the other end of the spectrum 386 Litchfield 2018⁴⁵ assessed the outcome measure at a single time point only four months after 387 the interventions were deployed using a proxy measure for ARI; meaning that this study could 388 not be included within the meta-analysis as it was not a rate. Smith et al., 2011⁴⁸ completed 389 390 weekly visits over 14-18 months to determine the number of ARI episodes. Additionally, only six out of eight studies observed ARI outcomes in children after six months of age, as new 391 392 stove use has been observed to reduce and stabilise after 200 days after intervention deployment,⁶³ therefore short follow up duration would be an overestimate of stove use and 393 raises potential comparison issues between pre and post six month ARI estimates. 394

As well as simultaneous use of multiple domestic fuels and/or cooking apparatus – 'stacking', a change in stove use over time and the observed low levels of compliance may explain the heterogeneity observed in both health benefits and harms. Conclusions about the role of compliance in uptake and sole use of the intervention are limited, as self-reported measures do not capture if the stove is in good condition⁶⁴ and may be an overestimate, due to subject

to observer or social acceptability bias.⁶⁵ Mortimer et al. 2017⁴⁶ attempted to use stove 400 401 monitors for objective assessment with limited success. Stove monitoring would allow participants to be blinded for stove usage compliance observations but would not provide 402 detail of fuel or stove stacking.⁶⁵ In addition, intervention stove use typically waned over time 403 due to disrepair, with study investigators often providing resource for repairing and replacing 404 stoves, thereby potentially reducing real-life applicability and generalisability. The Nigerian 405 406 Ethanol cookstove intervention team provided health promotion advice on how to reduce pollution^{35,50} to all which may be why there was a smaller difference between intervention 407 and control groups; however it does present a more realistic real-world scenario. In addition, 408 409 educational packages are often lacking for many interventions, but may provide a vital tool to encourage uptake and improve long-term compliance. A lack of compliance may also be the 410 underlying reason as to why only two out of the eight studies with reported HAP 411 412 measurements achieved levels below the WHO-IAQ levels, consistent with other findings;¹⁷ 413 however there were differences in air pollutant measurement type, location, duration between the studies and potential attenuation through neighbours not receiving the intervention.¹⁵ In 414 addition, those studies reporting a reduction in HAP between the intervention and control, did 415 not alter the summary effect size for birthweight (n=2; Appendix 7), LBW (n=2; Appendix 8) 416 417 and ARI (n=2; Appendix 9). Few studies investigated an exposure-response relationship, which limits any discussion on the presence of an exposure-response relationship in the 418 absence of any treatment effect. 419

As all the identified eligible interventions were structural or clean fuel transitional
interventions, albeit it within the limitations of the search strategy (e.g., synonyms of cleaner
fuels), we identified a knowledge gap concerning the effectiveness of behavioural and
community led interventions (e.g., outdoor cooking, using dry wood, ventilation) to reduce
maternal and child health harms of HAP exposure. Short-term harm reduction, community-

led, initiatives should not be neglected, as they have the potential to reduce $exposure^{66-68}$ and 425 deliver a health benefit.⁶⁹ Future interventions need to take into consideration contextual, 426 community and end-user needs,^{7,16} including engagement with government, stakeholders and 427 investors;⁷⁰ so that the community can continually invest in interventions to maintain 428 sustained usage.⁷¹ The RCT study design allows for a robust comparison of the benefits of the 429 intervention enabling higher methodological quality assessment, investigation of the 430 exposure-response relationship,⁷² and evaluation of socioeconomic implications.⁷³ However, 431 study periods are often relatively short and participants are encouraged/incentivised to use and 432 engage with the interventions,⁴⁵ and so they typically fail to fully account for decreasing 433 434 intervention uptake and usage over time, thereby limiting the achievement of a sustained HAP exposure reduction and health benefits.⁴⁴ Additionally, multi-disciplinary studies should 435 address improved criteria/procedures for assessment of health outcomes, (as existing studies 436 437 have been identified as adopting unclear and inconsistent health outcome definitions), alongside independent objective assessment (e.g., by healthcare workers) of health outcomes 438 to aid blinding and reduce risk of observation bias. Our recommendations to improve the 439 evaluation of HAP intervention measures, require appropriate research funding investment, 440 resources and expertise to undertake such trials of complex intervention measures in low-441 income settings. Complex interventions may be difficult to standardise,¹ and improvements 442 which could help reduce variation between trials should be encouraged whilst not unduly 443 limiting innovation in intervention development. 444

The systematic review highlights the variation in study design, intervention type and outcome, which limits the number of comparable studies. Therefore, it was not possible to wholly address uptake and efficacy of HAP interventions; but only to identify and assess quantitative data reporting the relationship between intervention (e.g. ICS/fuel) uptake and maternal and child health outcomes. Despite the potential documented benefit of ICS, there is a move away

from ICS to cleaner fuel to be able to achieve the WHO-IAQ and address the health impacts 450 451 of HAPs, due to the exposure-response curves indicating a need for reduction to very low levels. The HAPIN trial,⁷⁴⁻⁷⁶ an ongoing four country LPG stove RCT, with rigorous methods 452 including free fuel to incentivise compliance, could provide important results to strengthen 453 the evidence for new and existing child and maternal health outcomes. We recommend large 454 scale trials reporting multiple health, HAP and uptake outcomes adhering to full reporting 455 456 procedures including a summative assessment of all outcome measures in a published article, providing better reporting and dissemination of the benefits of such interventions. In addition, 457 no study were found reporting exposure to HAP from heating and lighting. Households have 458 459 little or no choice of alternative options and is likely to be a major source, therefore altering cooking practice where heating is required will have little effect on exposure. Conversely 460 there are other good options of lighting intervention (e.g., solar lamps) which can be explored. 461 This review highlights an existing research gap in short-term transitional harm reduction 462 interventions, which are required to make air quality and health improvements in the short 463 term. It could be argued that in countries with limited resources there should be a focus on the 464 consolidation of existing evidence, which while relatively weak, can be useful for developing 465 actionable evidence for policymakers⁷² on the effectiveness as well as facilitators and barriers 466 467 to implementation and adoption of HAP interventions.

468 5. Conclusion

This systematic review shows that ICS interventions have the potential to reduce ARI risk among those living in high altitude settings, incident burns in children under five years and risk of LBW. However, there are future research and policy implications for funding and development of effective community orientated short-medium and long-term household intervention measures, which should be adequately investigated using robust study

| 474 | methodology. | These interv | ventions may | / deliver a | a substantial | benefit for | r child and | l maternal |
|-----|--------------|--------------|--------------|-------------|---------------|-------------|-------------|------------|
| | | | | | | | | |

475 health, and would help support sustainable development in LMIC settings worldwide.

476 Author Contributions

- 477 **KEW**: Conceptualisation, methodology, data curation, formal analysis, visualisation, writing
- 478 original draft. **EDC**: Conceptualisation, methodology, data curation, Writing review &
- 479 editing. DJM: Methodology, Writing review & editing. MJP: Methodology, Writing -
- 480 review & editing. HLL and JS: Data curation, Writing review & editing. SEB:
- 481 conceptualisation, supervision, reviewing and editing, SMH and GNT: Supervision, Writing
- 482 review & editing. RD, FDP, SMG and DW: Writing review & editing

483 **Conflict of interest statement**

484 We declare no competing interests

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760 Artwork and Tables with Captions

761 Tables

762 Table 1: Study eligibility PICOS criteria

| Populations | Pregnant women | | | |
|---------------|---|--|--|--|
| | Children under five | | | |
| Interventions | Household air pollution intervention | | | |
| Comparators | Standard practice or alternative intervention | | | |
| Outcomes | tcomes Pregnancy outcomes: IUGR, birthweight, preterm birth, pre | | | |
| | eclampsia, gestational diabetes, maternal mortality, | | | |
| | perinatal/infant mortality, stillbirth and miscarriage | | | |
| | Child health outcomes: upper and lower respiratory tract | | | |
| | infections, pneumonia, asthma, respiratory distress syndrome, | | | |
| | otitis media, impaired neurodevelopment, mortality and burns | | | |
| Study designs | Randomised control Trials | | | |
| | Non-randomised control trials | | | |
| | Quasi-experimental or natural experiments | | | |

Table 2: Methodological, outcome and situational characteristics of included studies

| Publication | Study type | Intervention and | Control | Population | Eligibility criteria | Health outcomes and definitions | Follow up | Household air | Compliance | Geographical characteristics | Study Quality ¶ |
|---|---|--|--|--|---|--|--|--|---|---|--------------------|
| | | time of derivery | | | | uciliitions | periou | measurements | | char acter istics | Quanty |
| | | | | | Pregna | ncy Outcomes | | | | | |
| Ahmed <i>et al.</i> , $(2015)^{34}$ § | C-RCT N=1267 | ICS – "\$100 cookstove" n=628 | Traditional cookstove (biomass fuels) n=639 | Pregnant women | 8-12 weeks gestation at time of enrolment | LBW – measured at home or a health care facility within 72 hours of delivery | 8-12 weeks gestation until 42-day post- partum | None taken | Not reported | Shahjadpur sub- district, Bangladesh | Weak |
| Alexander <i>et al.</i> (2017) ³⁵ | RCT N=324 | Ethanol Clean Cookstove and information on the dangers of smoke exposure and how to reduce exposure. | Standard practice: firewood or kerosene and given information on the dangers of smoke exposure and how to reduce | Pregnant women attending antennal clinics who cook on Kerosene or firewood | Have a child between 2-8 months Cooks in an enclosed cookhouse Mother is not | Blood pressure (SBP and DBP) taken at 20 weeks, 26 weeks, 30 weeks, 34 weeks, 38 weeks. An average of three reading recorded after being seated for 10 minutes and on the left arm. | 18-38 weeks gestation | Reported in Alexander 2018 | Not reported | 9 selected village in Ibadan Nigeria, peri-urban setting | Strong |
| Alexander <i>et al.</i> (2018) ³⁶ | | n= 162 | exposure. Data was extracted for the firewood only control group. n= 162 | | HIV positive or a smoker Does not live with a smoker Does not cook for a living Has not previously has a high risk pregnancy | Birthweight (g) Preterm (delivery before 37 weeks gestation) Stillborn (death after 24 weeks gestation) Miscarriage (Fetal loss before 24 weeks) Gestational age (weeks gestation at birth) Birth length (cm) Head Circumference (cm) Respiratory rate (breaths/min) Neonatal death Birth defects Perinatal mortality (Stillbirth or neonatal death) | 18 weeks gestation to 6 weeks post pregnancy | 72 hours personal $PM_{2.5}$ Rainy season – Intervention = n=114, Mean (SD) 61(74) μ g/m ³ Control = n=116 Mean (SD) = 66(82) μ g/m ³ Dry Season – Intervention = n=99, Mean (SD) = 118(166) μ g/m ³ Control = n=98 Mean (SD) = 102 (102) μ g/m ³ | Not reported | | |
| Hanna <i>et al.</i> (2016) ³⁷ | RCT N= 2575 | Three phases. Gram Vikas improved stove received by 1/3 is phase one and another 1/3 in phase two | Traditional cooking (firewood, crop residue, or cow dung). The last 1/3 received Gram Vikas improved stove at the end. | Participants residing in households within study area | Not stated | Birthweight, stillbirth or miscarriage and infant mortality. No definition provided, but were self- reported | Stove placement and follow up occurred between 2006- 2010 (4 years) | Personal Exhaled CO (Micro Medical CO monitor) Intervention difference from baseline: -0.23ppm (SD:0.196) Control Mean: 7.128 ppm | Self-reported stove use. 60% of participants reported correct usage. | Orissa States, Rural India where 40% live below the poverty line | Weak |
| Katz <i>et al.</i> (2020) ³⁸ | Step-wedge RCT Nepal Cookstove Intervention Project Trial 1: N= 3706 (2397 live | Trial 1: ICS Environfit International (Proportion of pregnancy exposure to ICS, <33, 33-65, 66-99, 100%) | Trial 1: Traditional biomass cooking (i.e. ICS was given after birth). Trial 2: LPG stove vs. ICS n= 270 | Married women age 15-30 | Household has one married women (15- 30 years), a child under 36 months and does not already use LPG stove or electricity | Birthweight (g) taken within 72 hours of birth LBW (≥2500g) Gestational Age (weeks) Preterm (before 37 weeks) SGA (sex and gestational- age-specific birthweights fell below the 10th percentile of | Women recruited before conception and followed up until birth. Birth included coloured over a 2-year period | Stove area measurements (Av. 21.7 hours) Trial 1: PM _{2.5} : TB = Mean: 1380 µg/m ³ (95% CI: 1336, 1425) | Weekly visit to encourage and check stove use. Trial 1 : 90% reported use of alternative | Village development communities in rural southern low land Nepal, relying on subsistence farming | Strong |

| | births separated | Trial 2: LPG stove | | | | the inter-growth population | for trial 1 and | ICS = Mean 936 | stove at least | | |
|----------------------------|------------------|---------------------|--------------------|-----------------|----------------------|------------------------------|-------------------|-------------------------------|------------------|------------------|----------|
| | by gestation in | n = 279 | | | | distribution using the upper | 1-year period | ug/m ³ (95% CI: | once per week | | |
| | nregnancy ICS | | | | | bounds of weekly published | for trial 2 | 895 978) | Trial 2. | | |
| | pregnancy reb | | | | | data | 101 1111 2. | CO(TD = Maan | Alternative | | |
| | was deployed) | | | | | data | | 110 (050) CI | Alternative | | |
| | Trial 2: N= | | | | | | | 11.0 ppm (95% CI: | stove use was at | | |
| | 1851 | | | | | | | 10.6,11.4), ICS = | 50% | | |
| | | | | | | | | Mean 6.7 ppm (95% | | | |
| | | | | | | | | CI: 6.4.7.1) | | | |
| | | | | | | | | Trial 2. | | | |
| | | | | | | | | $DM \rightarrow ICS = 885$ | | | |
| | | | | | | | | $F_{12,5}$. ICS = 885 | | | |
| | | | | | | | | μg/m ³ (95% CI: | | | |
| | | | | | | | | 810,959) | | | |
| | | | | | | | | $LPG = 442 \ \mu g/m^3$ | | | |
| | | | | | | | | (95% CI: 405,482) | | | |
| | | | | | | | | CO: ICS = Mean | | | |
| | | | | | | | | 5 5ppm (95% CI: | | | |
| | | | | | | | | 5.0 6 0) | | | |
| | | | | | | | | 5.0,0.0 | | | |
| | | | | | | | | LPG = Mean 1.7 | | | |
| | | | | | | | | ppm (95% CI: | | | |
| | | | | | | | | 1.5,1.9) | | | |
| Thompson et | RCT – | Chimney stove | Open wood fires | Pregnant | Households with a | Birthweight measured within | ICS was | 48 hours personal | Weekly | San Marcos, a | Moderate |
| al. $(2011)^{39}$ | RESPIRE | n=134 | (firewood) n=120 | women | pregnant women or | 48 hours of delivery. Low | received by | CO. | fieldworker | rural and high | |
| × / | N=266 | | ` ' | | a child < 4 months | birthweight defined at | participants in | Open fire n=54 | home visits to | altitude part of | |
| | | | | | of age who cook on | <2500g | the latter stages | mean = 4.1 ppm | check function | Guatemala. | |
| | | | | | open wood fires | 20008 | of pregnancy | (SD:3.2) (GM | and arrange if | Guardinana | |
| | | | | | open wood mes | | of pregnancy | (3D.3.2)(OM) | and arrange fi | | |
| | | | | | | | | 5.2(5D:1.9)) | repair needed. | | |
| | | | | | | | | Chimney n=49 | Observations | | |
| | | | | | | | | mean 2.5ppm | not reported | | |
| | | | | | | | | (SD:2.5) GM | | | |
| | | | | | | | | (1.8(2.1)) | | | |
| Wylie (2017) ⁴⁰ | RCT – | Biolite improved | Three stone stove | Pregnant | Primary cook at less | Birthweight (g) measured | Stove deployed | Reported in Ouinn | Weekly stove | Rural Ghana | Strong |
| +8 | GR APHs+ Trial | cookstove(n=527) | (firewood) $n=526$ | women at 28 | than 28 weeks | within 24 hours of delivery | at 28 weeks | et al 2017 ⁵¹ | use compliance | | 0 |
| +8 | | and LPG cookstove | (Inewood) II 520 | weaks gestation | destation cooking | Preterm birth and SGA | actation and | 72 hours personal | by | | |
| | | | | weeks gestation | | | gestation and | | C 11 1 | | |
| | | (n=361) | | | on traditional fire, | details obtained | women | CO. | fieldworkers. | | |
| | | | | | and are a non- | | followed to | Mean ICS: 1.43 | Observations | | |
| | | | | | smoker | | delivery | ppm | not reported | | |
| | | | | | | | | Mean Control: 0.63 | | | |
| | | | | | | | | ppm | | | |
| | • | | • | | Under fiv | e child outcomes | • | | | | |
| Adane et al. | C-RCT N=5508 | Injera baking stove | Traditional | Children under | Exclusive use of | Trained nurse diagnoses ARI | Over 1 vear | Reported in Adane | Self-report. | A low-income | Strong |
| $(2021)^{41}$ | Pre-enrolment | n=2750 | biomass stove | 4 years from | traditional biomass | using the IMCI pneumonia | from receiving | et al (2021) ⁷⁸ | direct field | rural community | Sucue |
| (2021) | aross sostional | 11 2750 | n-2758 | hiomaga | stava in an analasad | algorithm | intervention | One cookiEng hour | abconvotion and | in Ethionic | |
| | ADI and 1 | | 11-2/30 | oronass | stove in an enclosed | argoritumi. | intervention, | One cookiring nour | | in Europia | |
| | AKI prevalence | | | cooking low | cooking area. | Burns were reported | taking | area PM _{2.5} | unannounced | | |
| | 1s reported | | | income | | | measurements | Control: Mean 805 | visits. | | |
| | elsewhere 77 | | | households | | | at three months | μg/m ³ (95% CI: | Observations | | |
| | | | | | | | intervals | 794-817). | not reported | | |
| | | | | | | | | Intervention: Mean | 1 | | |
| | | | | | | | | 465 µg/m ³ (95% CI | | | |
| | | | | | | | | 458_472) | | | |
| Horris at al | Interrupted time | ONIL store | Traditional | Whole | | Nurse diagnosed Aguto | A vears over | None taken | Not reported | Quiche region of | Weak |
| $(2011)^{42}$ | antinupieu tille | ONIL SIOVE | riautional | wildle | - | wise diagnosed. Acule | + years, over | INOTIC TAKETI | Not reported | Customala | w cak |
| (2011) | series | | Cooking | population | | (AUDD) N 1 | which time the | | | Guatemala | |
| | N=4026 | | (firewood) | attending a | | (AURI) = Non-productive | ICS was | | | | |
| | 1 | | 1 | basic health | | cough, nasal congestion and | 1 | | | | |

| | | | | care clinic in the village of Santa Avelina | | sore throat, with or without low-grade fever ALRI = Non-productive cough, nasal congestion and sore throat, with fever>38°C | installed in 90% of homes | | | | |
|---|------------------|--------------------------------|---|---|---|--|---|---|--|---|--------|
| Hartinger <i>et al.</i> (2016) ⁴³ | C-RCT N=534 | OPTIMA-improved stove n=267 | Traditional stoves or open fires (solid fuels) n=267 | Children under than age of 36 months residing in traditional biomass cooking households | Use of solid fuels, no public sewage connection and no intention to move during the study period | Symptoms observed by trained fieldworkers ARI = cough and/or difficulty breathing. ALRI = cough or difficulty breathing, with a raised respiratory rate (>50 per min in children aged 6– 11 months and >40 per min in children aged >12 months) on two consecutive measurements. | Followed up for 12 months, counting weekly ARI events | Reported in Hartinger et al., (2013) ⁷⁹ 48 hours personal and kitchen are PM _{2.5} and CO. Kitchen PM - Control n=34 mean:189 µg/m ³ (95% CI:116-261) Kitchen PM Interventions n=30 mean: 148 µg/m ³ (95% CI:88-208) Personal PM Control n=40, Mean:129 µg/m ³ (95% CI:88-208) Personal PM Control n=40, Mean:129 µg/m ³ (95% CI:82-176) Personal PM intervention n=37 Mean:104 µg/m ³ (95% CI:64-144) Kitchen CO control n=44 mean:5.8 ppm (95% CI:2.8-6.6) Personal CO control n=45 mean: 1.4 ppm (95% CI:0.8-2) Personal CO intervention n=39 mean: 1.5 ppm (95% CI:1-2) | Spot checking and monthly self-reported stove use. 90% of mother reported using the ICS. | High evaluation, rural small farming community in Peru | Strong |
| Kırby <i>et al.</i> , (2019) ⁴⁴ | C-RCT N= 2174 | ICS n=1073 | Traditional biomass cooking (charcoal, wood, crop residue) n=1101 | Children under the age of five | Agreed to receive intervention and a child under 4 years | Mother reporting child's symptoms to fieldworkers 7-day ARI: cough accompanied by rapid breathing or difficulty breathing. Current IMCI pneumonia: cough and difficulty breathing, accompanied by chest in drawing and/or rapid breathing ≥40 breaths/minute for children ≥12 months or | 3 tollow up visits at approximately 4 month intervals | Yes – 48 hours PM _{2.5} measurement every three months n=148 Intervention: Mean: 224 μ g/m ³ (median 154 μ g/m ³ (median 154 μ g/m ³) Control: Mean: 231 μ g/m ³ (median 161 μ g/m ³ , IQR 91–285 μ g/m ³) | Self-report and direct observation by trained field enumerators at each field visit. Declining use throughout study period, with 52.5% using intervention | Western rural Rwanda 9 96 administrative sectors containing 3,612 villages, with a total population of about 2.5 million persons) | Strong |

| | | | 0 | | | | | | | | 0 |
|--|---------------------------|---|--|---|---|---|--|--|---|---|----------|
| | | | | | | ≥50 breaths/minute for children 2–12 months. Current Severe pneumonia (IMCI)‡ cough or difficulty breathing accompanied by severe symptoms (not able to drink, persistent vomiting, convulsions, lethargic/unconscious, stridor in a calm child, or severe malnutrition). Does not include children <2 months. | | | every day by the third visit, with stove use being over reported (ref – Thomas et al 2016) | | |
| Litchfield | RCT N=226 | ICS and briquettes | Traditional three | Woman and | Cooking solely on | Burns in previous two months Pneumococcal | Followed up | Yes – 48 hours | Self-report and | Kombo East | Strong |
| (2018) ⁴⁵ | | n=115 | stone stove (wood) n=136 | children in wood cooking households | biomass, in an enclosed cookhouse with a child between 2-8 months | nasopharyngeal carriage was defined as a proxy for ARI | over 4 months after intervention | $\begin{array}{c} PM_{2.5} \text{ and CO stove} \\ \text{located} \\ \text{measurements} \\ PM_{2.5} \text{ Intervention} \\ \text{Mean} = 659.8 \ \mu\text{g/m}^3 \\ \text{(SD:827.7), Control} \\ \text{Mean} = 573.1 \ \mu\text{g/m}^3 \\ \text{(SD:134.3)} \\ \text{CO: Not reported} \end{array}$ | fieldworkers checked compliance during weekly fuel drop offs. 41.4% continued to use 3-stone stove | District, rural Gambia | |
| Mortimer <i>et al.</i> (2017) ⁴⁶ | C-RCT CAPS N= 10750 | ICS (Philips HD4012LS biomass fan stove) n=5400 | Traditional cooking on open fires n=5350 | Children under the age of 4.5 years | Children under 4.5 years, continuous recruitment throughout the study as children become eligible, up until 6 months before the study end. | Assessed by trained healthcare staff. Non-severe IMCI pneumonia: cough or difficulty breathing and fast breathing (60, 50, or 40 breaths per min or higher in those aged <2 months, 2–12 months, and 1–5 years, respectively). Severe IMCI pneumonia: addition of chest in-drawing, stridor, or any general danger sign (inability to drink or breastfeed, vomiting, convulsions, lethargy, or unconsciousness). Death, burns and asthma was also recorded as adverse events | Followed up for every three months 2 years or until the end the trial which is ever is sooner | None taken | Self-report and stove use monitors were placed on one of the stoves in a randomly selected 10% sample of intervention households to record temperature fluctuations. Number of cooing event per day; Year 1: Mean:0.51 (SD:0.55) Year 2: Mean:0.34 (SD:0.40). After two year 50% reported using intervention | Sothern Shire river valley (Chikhwawa) and Northern (Karonga) Malawi | Strong |
| $al. (2015)^{47}$ | KC1 N=008 | raisan siove n=338 | partial use of | 4 years old | inclusion criteria | Lower respiratory infection - | for 10 months | (n=113) with a | Not reported | Six rurai communities in | woderate |
| | | | | residing in fuel | mentioned | last breatning, cough and | 1 | | | the highland of | |

| | | | intervention | wood | | difficulty breathing, Upper | | range 500-1000 | | Michoacan, | |
|------------------------|------------------|----------------|-----------------|-----------------|----------------------|------------------------------|------------------|------------------------------|-----------------|------------------|----------|
| | | | n=330 | households | | respiratory infection cough, | | $\mu g/m^3$. | | Mexico | |
| | | | | | | congestion phlegm and sore | | Intervention | | | |
| | | | | | | throat | | Median:200 µg/m ³ | | | |
| | | | | | | | | Control median: 300 | | | |
| | | | | | | | | µg/m ³ | | | |
| | | | | | | | | Reporting an 80% | | | |
| | | | | | | | | reduction | | | |
| Smith et al. | C-RCT | Chimney stove | Open wood fires | Children under | Households with a | Physician diagnosed ARI, | Weekly visits | Personal 48 hours | Weekly | San Marcos, a | Strong |
| $(2011)^{48}$ | RESPIRE | n=269 | n=265 | 4 months | pregnant women or | with chest radiography and | for 14-18 | CO every 3 months. | fieldworker | rural and high | |
| | N=534 | | | | a child <4 months of | RSV testing following | months | 50% reduction | home visits to | altitude part of | |
| | | | | | age that cooked on | standard practice. | | Intervention: 1.1 | check function | Guatemala. | |
| | | | | | open wood fires | Trained fieldworker | | ppm | and arrange if | | |
| | | | | | | diagnosed ARI using WHO | | Control: 2.2 ppm. | repair needed. | | |
| | | | | | | IMCI algorithm. | | | Observations | | |
| | | | | | | | | | not reported. | | |
| Tielsch et al. | Step-wedge | ICS environfit | Traditional | Household with | Household has one | ARI: Maternal report of 2 or | Weekly | HAP measurement | Weekly visit to | Rural southern | Moderate |
| (2016) ⁴⁹ § | RCT measuring | international | biomass cooking | a married | married women (15- | more consecutive days of | maternal reports | taken but no results | encourage and | low land Nepal, | |
| | before and after | | | woman (15-30 | 30 years), a child | fast or difficult breathing | over 6 months | reported | check stove | village | |
| | respiratory | | | years) and a | under 36 months | accompanied by fever | | | use. | development | |
| | incidence | | | child under the | and does not already | ALRI, cough, wheeze, burns | | | Observations | communities | |
| | Nepal | | | age of 36 | use LPG stove or | also recorded | | | not reported. | based on | |
| | Cookstove | | | months | electricity | | | | | subsidence | |
| | Intervention | | | | | | | | | farming | |
| | Project N=5254 | | | | | | | | | | |

N=Number study n=number randomised to each group, C-RCT = Cluster randomised control trial. GM=geometric mean. ICS = Improved cookstove \ddagger IMCI = Integrated Management of Childhood Illnesses. \ddagger Quinn *et al.*, 2017⁵¹ was a convenience sample from GRAPHs (N=44) reporting blood pressure 3-4 weeks after intervention was deployed.

[‡] Asante et al., 2019⁸⁰ stated no observed effect on pneumonia in children under five between the intervention and controls as part of the GRAPHS study. No results were reported, therefore not included.

\$ These studies are conference abstract and authors were contacted to provide further details to no avail. Wylie et al. 2017⁴⁰ and Tielsch et al. 2016⁴⁹ are part of large RCT, supported by other published evidence. Ahmed et al. 2015³⁴ has not published the "\$100 cookstove" trial, to the best of our knowledge, since the publication of the conference abstract in 2015.

¶ The breakdown of the study quality can be found in appendix 10.

Table 3: Included study health outcome results

| Publication | Intervention | Control | Effect estimate |
|---|---|---|---|
| Pregnancy outcomes | | | |
| Ethanol cookstoves - Ethanol vs firewood | 1 | | |
| Blood pressure (mm Hg) - Alexander <i>et</i> <i>al.</i> (2017) ³⁵ | Normal blood pressure:39/48 Pre-hypertension:8/48 Hypertension:1/48 | Normal blood pressure:42/53 Pre-hypertension:12/53 Hypertension: 1/53 | Hypertensive verse non-hypertensive - Fisher's exact - $p=0.10$ |
| Birthweight (g) - Alexander <i>et al.</i> $(2018)^{36}$ | Mean:3081 g, SD:470, n=50 | Mean:2942, SD:403, n=48 | AMD:197 (95% CI: 25–368) Adjusted for marital status and BMI |
| Gestational age (weeks) - Alexander <i>et</i> $al. (2018)^{36}$ | Mean:39.4, SD:1.6, n=51 | Mean:37.9, SD:5.5, n=54 | AMD:1.6 (95% CI: 0.04–3.2) Adjusted for marital status and BMI |
| Birth length (cm) - Alexander <i>et al.</i> $(2018)^{36}$ | Mean:46.6, SD:5.3, n=50 | Mean:46.4, SD:5.4, n=47 | Calculated† MD:0.2, SD:8 Reported <i>p</i> =0.92 |
| Head Circumference (cm) - Alexander et al. (2018) ³⁶ | Mean:33.8, SD:2.9, n=50 | Mean:34.3, SD:2.1, n=48 | Calculated† MD:-0.5, SD:4 Reported p=0.3 |
| Respiratory rate (breath/min) - Alexander <i>et al.</i> (2018) ³⁶ | Mean:125, SD:20.1, n=49 | Mean:123, SD:10.7, n=46 | Calculated† MD:2, SD:23 Reported <i>p</i> =0.53 |
| Preterm birth - Alexander <i>et al.</i> (2018) ³⁶ | 5/51 | 5/54 | Calculated† OR:1.07 (95% CI:0.29-3.9) Reported <i>p</i> =1.0 |
| Stillborn - Alexander <i>et al.</i> $(2018)^{36}$ | 0/51 | 2/54 | OR could not be calculated Reported $p=1.0$ |
| Miscarriage - Alexander <i>et al.</i> (2018) ³⁶ | 0/50 | 1/46 | OR could not be calculated p=0.058 |
| Birth defects - Alexander <i>et al.</i> $(2018)^{36}$ | 0/50 | 0/50 | OR could not be calculated Reported <i>p</i> =1.0 |
| Neonatal death - Alexander <i>et al.</i> $(2018)^{36}$ | 0/51 | 0/54 | OR could not be calculated $p=1.0$ |
| Perinatal mortality - Alexander <i>et al.</i> $(2018)^{36}$ | 0/51 | 1/46 | OR could not be calculated Reported <i>p</i> =0.058 |
| Improved cookstove (ICS) | | | |
| Birthweight (g) | | | Colordate H MD: 24 SD:77.4 |
| | Mean:2930, SD:985, n=241 | Mean:2964, SD:886, n=400 | Reported p=0.49 |
| Katz <i>et al.</i> $(2020)^{38}$ | ICS <33% - Mean:2628, SD:443, n=133 | | AMD: -12.8 (95% CI: -107.1-81.4) |
| | ICS 33-65% - Mean:2647, SD:418, n=116 | Mean: 2630, SD:443, n=558 | AMD: -7.7 (95% CI: -112.7–97.4) |
| | ICS 66-99% - Mean:2676, SD:408, n=104 | | AMD: 28.9 (95% CI: -87.2–145.0) |
| | ICS 100% - Mean:2657, SD:439, n=360 | | AMD: -5.5 (95% CI: -122.6–111.6) Adjusted for secular trends and sex of infant |
| Thompson <i>et al.</i> $(2011)^{39}$ | Mean: 2797 (95% CI:2697, 2896), n=69 | Mean: 2729 (95% CI:2654 to 2804) n=105 | Beta coefficient 89g (95% CI: -27 to 204) <i>p</i> -value 0.13 Adjusted for height, gravidity, diastolic blood pressure and season of birth |
| Wylie (2017) ⁴⁰ | Mean 2920, SD:460, n=488 | Mean = 2890, SD:490, n=475 | Calculated [†] MD: 30, SD: 30.6 |
| Preterm birth | | | |
| Katz <i>et al.</i> $(2020)^{38}$ | ICS <33%: 39/165 | | ARR:1.38 (95% CI:0.97–1.97) |
| | ICS 33-65%: 19/141 | | ARR:0.81 (95% CI:0.50–1.32) |
| | ICS 66-99%: 27/125 | 212/943 | ARR:1.41 (95% CI:0.91–2.20) |
| | ICS 100%: 105/474 | | ARR:1.66 (95% CI:1.08–2.57) Adjusted for secular trends and sex of infant |

| Wylie (2017) ⁴⁰ | 17/488 | 24/475 | Calculated [†] OR:1.02 (95% CI:0.32–1.38) |
|--|--------------------------------------|---------------------------------|---|
| Low birth weight | | | |
| Ahmed <i>et al.</i> $(2015)^{34}$ | | | Control (intervention as reference): AOR:1.76 (95% CI: |
| | 110/460 | 170/400 | 1.31-2.38) p < 0.001 |
| | 110/409 | 1/9/499 | Aujusted for maternal age, maternal parity, DMI, |
| | | | spend for cooking, husband smoking, SpCO 1 st trimester |
| Katz <i>et al.</i> (2020) ³⁸ | ICS <33%: 62/118 | | ARR:1.14 (95% CI:0.90, 1.44) |
| | ICS 33-65%: 4/166 | | ARR:0.83 (95% CI:0.59,1.17) |
| | ICS 66-99%: 35/104 | 227/588 | ARR:0.92 (95% CI:0.63,1.34) |
| | ICS 100%: 116/360 | | ARR:0.95 (95% CI:0.65, 1.30) |
| 771 | | | Adjusted for secular trends and sex of infant |
| Thompson <i>et al.</i> $(2011)^{33}$ | 12/(0 | 26/105 | AOR: 0.74 (95% CI:0.33–1.66) Adjusted for maternal |
| | 15/09 | 26/103 | season of hirth |
| Wylie (2017) ⁴⁰ | 77/488 | 83/475 | Calculated† OR:0.88 (95% CI:0.21–1.24) |
| Small for gestational age | | | |
| Katz <i>et al.</i> (2020) ³⁸ | ICS <33%: 62/118 | | ARR:1.14 (95% CI:0.90–1.44) |
| | ICS 33-65%: 57/102 | | ARR:1.21 (95% CI:0.95–1.54) |
| | ICS 66-99%: 47/93 | 248/522 | ARR:1.11 (95% CI:0.83–1.48) |
| | ICS 100%: 146/331 | | ARR:1.00 (95% CI:0.74–1.34) |
| $W_{-1} = (2017)40$ | 102/499 | 00/475 | Adjusted for secular trends and sex of infant |
| Other pregnancy outcomes | 105/488 | 99/475 | Calculated OR:1.02 (95% CI:0.32–1.58) |
| Gestational age (weeks): Katz <i>et al</i> | ICS <33%: Mean: 38.4, SD:3.1, n=165 | | AMD -0.51 (95% CI: -1.03–0.001) |
| $(2020)^{38}$ | ICS 33-65%: Mean:39.2, SD:2, n=141 | | AMD 0.27 (95% CI: -0.30–0.39) |
| | ICS 66-99%: Mean:38.8, SD:2.7, n=125 | Mean:38.6, SD:2.7, n=948 | AMD -0.24 (95% CI: -0.75–0.39) |
| | ICS 100%, Magn. 28 5 SD: 2.7 = 474 | | AMD -0.75 (95% CI: -1.360.14) |
| | ICS 100%: Mean:38.5, SD:2.7, n=474 | | Adjusted for secular trends and sex of infant |
| Stillbirth/miscarriage: Hanna <i>et al.</i> (2016) 37 ± 1000 | 287/587 | 401/1060 | Calculated [†] OR:1.55 (95% CI: 0.6–1.88) |
| Infant Mortality: Hanna <i>et al.</i> $(2016)^{37}$ | 28/488 | 42/701 | Calculated ⁺ OR:0.96 (95% CI:0.45-1.6) |
| LPG stove | 20/100 | | |
| Birthweight (g): Wylie (2017) ⁴⁰ | Moon: 2870 SD: 400 $n = 240$ | Maan:2800 SD: 400 n=475 | Calculated [†] MD: -20, SD: 34.8 |
| | Mean. 2870, SD. 490, n= 540 | Mcaii.2890, SD: 490, ii–475 | Reported p=0.68 |
| LBW: Wylie (2017) ⁴⁰ | 59/340 | 83/475 | Calculated† OR:0.99 (95% CI:0.69–1.42) |
| Preterm birth: Wylie $(2017)^{40}$ | 17/340 | 24/475 | Calculated [†] OR:0.99 (95% CI:0.52–1.87) |
| SGA: Wylie $(2017)^{+0}$ | /5/340 | 99/4/5 | $\frac{\text{Calculated} \text{TOR: } 1.0/(95\% \text{ Cl: } 0.7/-1.5)}{\text{Line directed OB: } 0.0(95\% \text{ Cl: } 0.2, 1.5)}$ |
| Stillbirth: wylie (2017) | 6/346 | 15/490 | (adjustment not reported) |
| ICS compared to LPG stove | | | (wajasanen nov reported) |
| Katz et al. (2020) ³⁸ Birthweight (g) | LDC: March 2742 SD:421 == 207 | ICS: M2700 SD:427 188 | MD: -37 (95% CI: -122–47) |
| | LPG: Mean:2/42, SD:431, n= 207 | ICS: Meall:2/90, SD:427, II-188 | (adjustment not reported) |
| Katz et al. (2020) ³⁸ Gestational age | LPG: Mean: 39 SD:2.4 n=243 | ICS: Mean:39.2 SD:2.2 n=248 | MD: -0.3 (95% CI: -0.7–0.2) |
| (weeks) | El G. Medal.57, 55.2.1, 11 245 | 165. Weah.57.2, 55.2.2, if 246 | (adjustment not reported) |
| Katz <i>et al.</i> (2020) ³⁸ Preterm birth | LPG: 47/243 | ICS: 33/248 | RR:1.45 (95% CI: 0.97–2.19) |
| Kata at al (2020) ³⁸ LDW | L DC: 65/207 | | (adjustment not reported) |
| Katz et ul. (2020) LD W | LPU: 03/20/ | ICS: 44/188 | (adjustment not reported) |
| Katz et al. (2020) ³⁸ SGA | | | RR:0.98 (95% CI:0.79–1.21) |
| | LPG: 86/184 | ICS: 84/176 | (adjustment not reported) |
| Child health outcomes | | | × v 1 / |

| Improved cookstove (ICS) | | | |
|---|---|---|--|
| Acute Respiratory Infections | | | |
| Adane et al., (2021) ⁴¹ | Parartad in shild abcorrections | Poported in shild observations | AOR:0.95 (95% CI: 0.89–1.02) p=0.18 |
| | | | Adjusted for gender, age, baseline ARI, location of |
| | 1/52/9800 | 1808/9952 | cooking, cookstove, frequency of baking event, visit |
| Harris et al. (2011) ⁴² Acute upper | 2006: | 2002: | Demonstrate de martes |
| respiratory infection | <1 year: 123 cases, Rate: 96.1 per 100 person-years assuming | <1 year: 192 cases, Rate: 150 per 100 person-years assuming | refreentage decrease in rate: |
| 1 2 | constant population (n=128), based on 2006 census | constant population (n=128), based on 2006 census | <1 year 35.9%, p <0.05 |
| | 1-4 years: 214 cases, Rate: 37.8 per 100 person-years assuming | 1-4 years: 248 cases, Rate: 43.8 per 100 person-years assuming | 1-4 year: 15.7%, p<0.05 |
| | constant population(n=566), based on 2006 census | constant population (n=566), based on 2006 census | |
| | Calculated [†] combined ages (<1-4): 337 cases, Rate: 48.6 per | Calculated [†] combined ages (<1-4): 440 cases, Rate: 63.4 per | calculated percentage decrease |
| | 100 person-years (n=694) | 100 person-years (n=694) | <1-4:25.470 |
| Harris et al. (2011) ⁴² Acute Lower | 2006: | 2002: | |
| respiratory | <1 year: 24 cases, Rate: 18.8 per 100 person-years assuming | <1 year: 86 cases, Rate: 67.2 per 100 person-years assuming | Percentage decrease in rate: |
| | constant population (n=128), based on 2006 census | constant population (n=128), based on 2006 census | <1 year: 72.1%, p<0.05 |
| | 1-4 years: 82 cases, Rate: 14.5 per 100 person-years assuming | 1-4 years: 151 cases, Rate: 26.7 per 100 person-years assuming | 1-4 years: 45.7%, p<0.05 |
| | constant population (n=566), based on 2006 census | constant population (n=566), based on 2006 census | |
| | Calculated [†] combined ages (<1-4): 106 cases, Rate: 15.3 per 100 | Calculated† combined ages (<1-4): 237 cases, Rate: 34.1 per | Calculated [†] percentage decrease |
| | person-years (n=694) | 100 person-years (n=694) | <1-4: 55.3% |
| Hartinger et al. (2016) ⁴³ ARI and ALRI | Reported in person weeks | Reported in person weeks | ARI: Adjusted Risk ratio: 0.95 (95% CI:0.82-1.10) |
| | ARI: 831/2976 | ARI: 877/3012 | ARLI: Adjusted Risk ratio: 2.47 (95% CI:0.79–1.19) |
| | ALRI: 25/554 | ALRI: 40/563 | Adjusted for age |
| Kirby <i>et al.</i> (2019) ⁴⁴ | | | 7-day ARI APR: 0.75 (95% CI:0.60–0.93), p=0.009 |
| | Reported in child observations: | Reported in child observations: | Current Pneumonia: APR 0.87 (95% CI: 0.58–1.30) |
| | 7-day ARI: 283/2850 | 7-day ARI: 441/3084 | <i>p</i> =0.491 |
| | Current pneumonia: 41/2574 | Current pneumonia: 55/2829 | Severe Pneumonia: APR 0.75 (95% CI:0.45–1.24), |
| | Severe pneumonia: 26/2574 | Severe pneumonia: 40/2829 | <i>p</i> =0.256 |
| | | | Adjusted for age and gender |
| Litchfield (2018) ⁴³ ARI - Pneumococcal | 72/98 | 83/111 | Calculated [†] OR:0.93 (95% CI:0.62-1.42) |
| Carriage | | | |
| Mortimer <i>et al.</i> (2017) ⁴⁶ Pneumonia and | Reported in child-years: | Reported in child-years: | Pneumonia: IRR:1.01 (95% CI:0.91–1.13) p=0.80. After |
| severe Pneumonia | Pneumonia: 1255/7964 | Pneumonia: 1251/8027 | adjustment for baseline values |
| | IR:15.76 (95% CI:14.89–16.63) per 100 child-years | IR: 15.58 (95% CI:14.72–16.45) per 100 child-years | Severe Pneumonia: IRR:1.30 (95% CI:0.99–1.71) |
| | Severe Pneumonia: 186/7964 | Severe Pneumonia: 145/8027 | <i>p</i> =0.06 |
| | IR: 2.33 (95% CI:2.00–2.97) | IR: 1.80 (95% CI:1.51–2.09) | F ····· |
| Schilmann et al. (2015) ⁴⁷ Upper and | | | Upper ARI: AOR:0.840 (95% CI:0.689–1.025), |
| lower ARI | | | IRR:0.789 (95% CI:0.701–0.888) |
| | ICS (not reported) | Firewood (not reported) | Lower ARI: AOR:0.612 (95% CI:0.207–1.805), |
| | (lot reported) | The wood (not reported) | IRR:0.411 (95% CI:0.212–0.796) |
| | | | Adjusted for age, sex, vaccination, breastfeeding, |
| | | | nutritional status and household characteristics |
| | | | Upper ARI: AOR:0.943 (95% CI:0.786–1.176), |
| | | | IRR:0.900 (95% CI:0.788–1.028) |
| | Combined ICS and firewood use (not reported) | Firewood (not reported) | Lower ARI: AOR:0.873(95% CI:0.258–2.992), |
| | (F) | (() | IRR:0.682 (95% CI:0.349–1.333) |
| | | | Adjusted for age, sex, vaccination, breastfeeding, |
| | ~ | ~ | nutritional status and household characteristics |
| Smith <i>et al.</i> $(2011)^{+\circ}$ ARI | Reported in child weeks: | Reported in child weeks: | ARI Fieldworker diagnosed - all: Rate ratio: 0.91 (95% |
| | ARI Fieldworker diagnosed - all: 321/143/9 | ARI Fieldworker diagnosed - all: 340/13939 | CI:0.74–1.13) $p = 0.393$ |
| | AKI Fieldworker diagnosed - severe: 26/14/19 | AKI Fieldworker diagnosed - severe: 45/14310 | ARI Fieldworker diagnosed - severe: Rate ratio:0.56 |
| | Clinical ARI - all: $124/15529$ | Clinical ARI - all: 139/148/1 | (95% CI:0.32-0.97) p = 0.036 |
| | Chinical AKI - Severe: 00/15555 | Dhusiaian diagnasad radialagiaal maximania alli 44/1400 | Clinical ARI - all: Rate ratio:0.78 (95% CI:0.59–1.06) |
| | rnysician-diagnosed radiological pneumonia - all: 41/15558 | Physician-diagnosed radiological pneumonia - all: 44/14886 | |

| | Physician-diagnosed radiological pneumonia - severe: 25/15559 Physician-diagnosed RSV negative - all: 73/15542 Physician-diagnosed RSV negative - severe: 27/15564 Physician-diagnosed RSV positive - all: 43/15556 Physician-diagnosed RSV positive - severe: 30/15568 | Physician-diagnosed radiological pneumonia - severe: 28/14891 Physician-diagnosed RSV negative - all: 77/14877 Physician-diagnosed RSV negative - severe: 42/14899 Physician-diagnosed RSV positive - all: 43/14879 Physician-diagnosed RSV positive - severe: 27/14897 | Clinical ARI - severe: Rate Ratio: 0.67 (95% CI:0.45– 0.98) Physician-diagnosed radiological pneumonia - all: Rate Ratio:0.74 (95% CI:0.42–1.15) p =0.231 Physician-diagnosed radiological pneumonia - severe: Rate ratio = 0.68 (95% CI:0.36–1.33) p =0.234 Physician-diagnosed RSV negative - all: Rate Ratio:0.79 (95% CI:0.53–1.07) p =0.192 Physician-diagnosed RSV negative - severe: Rate ratio:0.54 (95% CI:0.31–0.91) p =0.026 Physician-diagnosed RSV positive - all: Rate Ratio:0.76 (95% CI:0.42–1.16) p =0.275 |
|--|---|--|--|
| Tielsch et al. (2016) ⁴⁹ ARI | Not reported | Not reported | AOR: 0.87 (95% CI:0.67–1.13) |
| Burns | | | |
| Adane <i>et al.</i> $(2021)^{41}$ | Reported in child observations: 41/9860 | Reported in child observations 51/9932 | IRR:0.80 (95% CI: 0.54–1.22 |
| Mortimer <i>et al.</i> (2017) ⁴⁶ | Reported in child-years: 9/7964 IR: 0.11 (95% CI: 0.04–0.19) | Reported in child-years: 10/8027 IR:0.12 (95% CI:0.05–0.20) | IRR:0.91 (95% CI:0.37–2.23) p=0.83 |
| Tielsch et al. (2016)49 | Not reported | Not reported | AOR:0.68 (95% CI:0.48-0.95) |
| Kirby <i>et al.</i> (2019) ⁴⁴ | Reported in child observation: 51/2850 | Reported in child observations: 112/3090 | APR:0.51 (95% CI:0.36–0.74) Adjusted for age and gender |
| Other child health outcomes | | | |
| Mortimer et al. (2017) ⁴⁶ Asthma | Reported in child-years: 6/7964 IR: 0.08 (95% CI:0.02-0.14) | Reported in child-years: 10/8027 IR:0.02 (95% CI:0.01-0.06) | IRR:3.03 (95% CI:0.51–18.11) p=0.22 |
| Mortimer et al. (2017) ⁴⁶ Death | Reported in child-years: 3/7964 IR:0.04 (95% CI:0.00–0.08) | Reported in child-years: 4/8027 IR:0.05 (95% CI:0.00–0.10) | IRR:0.76 (95% CI:0.17–3.37) <i>p</i> =0.71 |
| Tielsch et al. (2016) ⁴⁹ Persistent Cough | Not reported | Not reported | AOR: 0.91 (95% CI:0.85–0.97), |
| Tielsch et al. (2016) ⁴⁹ Wheeze | Not reported | Not reported | AOR:0.87 (95% CI:0.78–0.97) |

Abbreviation are: OR=Odds Ratio, ARO=Adjusted Odds Ratio, p=p value, RR=Relative Risk, IR=Incident Rate, IRR=Incident Rate Ratio, APR=Prevalence Ratio, MD=Mean Difference, AMD=Adjusted Mean Difference, TB = Traditional Biomass

† Odds ratio calculated from data provided ‡ Results obtained from raw data provided in supplementary material



Figure 1: PRISMA flow diagram of search result and study selection. \dagger Two studies were identified from alternative sources. Hanna *et al.*, 2016^{37} was identified from a previous systematic review Thakur *et al.*, 2018^{16} and Wylie *et al.*, 2017^{40} investigation into available publish literature from the identification of the GRAPHs study through the ClinicalTrials.gov search. \ddagger Incorrect population are those studies that did not meet the population inclusion criteria, which included those studies where children above the age of five were also investigated by data from children under five could not be extracted separately. \S Two child health outcome studies could not be included in the meta-analysis due to lack of data provided. Adane *et al.* (2020) was identified as pre-print by the search, with subsequent publication⁴¹ during manuscript preparation.

Figure 2: Article characteristics by geographical region, with interventions type for pregnancy outcomes and duration of follow-up from intervention deployed to health outcomes measurement for child health outcomes.

Figure 3: Forest plot for the differences in birthweight (grams) between ICS and traditional cooking. Number of observations = 3049. A random effects model was used. Abbreviations: g=grams, MD = Mean Difference, 95% CI = 95% Confidence interval, I^2 = percentage variability of the effect estimates as a result of heterogeneity rather than chance, τ^2 tausquared, Test of $\theta_i=\theta_j$: Q(3) = chi-squared with degrees of freedom, p = p value, Test of $\theta = 0$: z = z statistic for overall estimate.

Figure 4: Forest plot for the change in LBW between ICS and traditional cooking. Number of observations = 3456. A random effects model was used. Abbreviations: OR = Odds ratio, 95% CI = 95% Confidence interval, I^2 = percentage variability of the effect estimates as a result of heterogeneity rather than chance, τ^2 tau-squared, Test of $\theta_i = \theta_j$: Q(3) = chi-squared with degrees of freedom, p = p value, Test of $\theta = 0$: z = z statistic for overall estimate.

Figure 5: Forest plot for the change in SGA between ICS and traditional cooking. Number of observations = 2129. A random effects model was used. Abbreviations: OR = Odds ratio, 95% CI = 95% Confidence interval, I^2 = percentage variability of the effect estimates as a result of heterogeneity rather than chance, τ^2 tau-squared, Test of $\theta_i = \theta_j$: Q(2) = chi-squared with degrees of freedom, p = p value, Test of $\theta = 0$: z = z statistic for overall estimate.

Figure 6: Forest plot for the change in PTB between ICS and traditional cooking. Number of observations = 2811. A random effects model was used. Abbreviations: OR = Odds ratio, 95% CI = 95% Confidence interval, I^2 = percentage variability of the effect estimates as a result of heterogeneity rather than chance, τ^2 tau-squared, Test of $\theta_i=\theta_j$: Q(2) = chi-squared with degrees of freedom, p = p value, Test of $\theta = 0$: z = z statistic for overall estimate.

Figure 7: Forest plot of studies reporting rates of ARI, with definitions that are compared to the WHO IMCI criteria, between ICS and traditional cooking. Number of observations = 78962. A random effects model was used. Abbreviations: RR = Rate Ratio, 95% CI = 95% Confidence interval, I^2 = percentage variability of the effect estimates as a result of heterogeneity rather than chance, τ^2 tau-squared, Test of $\theta_i=\theta_j$: Q(5) = chi-squared with degrees of freedom, p = p value, Test of $\theta = 0$: z = z statistic for overall estimate, RCT = Randomised control trial.

Figure 8: Forest plot of studies reporting rates of ALRI, with definitions that are compared to the WHO IMCI criteria, between ICS and traditional cooking. Number of observations = 54343. A random effects model was used. Abbreviations: RR = Rate Ratio, 95% CI = 95% Confidence interval, I^2 = percentage variability of the effect estimates as a result of heterogeneity rather than chance, τ^2 tau-squared, Test of $\theta_i = \theta_j$: Q(4) = chi-squared with degrees of freedom, p = p value, Test of $\theta = 0$: z = z statistic for overall estimate, RCT = Randomised control trial.

Figure 9: Forest plot of studies reporting burns between ICS and traditional cooking. Number of observations = 41723. A random effects model was used. Abbreviations: RR = Rate Ratio, 95% CI = 95% Confidence interval, I^2 = percentage variability of the effect estimates as a result of heterogeneity rather than chance, τ^2 tau-squared, Test of $\theta_i = \theta_j$: Q(2) = chi-squared

with degrees of freedom, p = p value, Test of $\theta = 0$: z = z statistic for overall estimate, RCT = Randomised control Trial.

Appendices

Appendix 1: MEDLINE search strategy (n=4306)

Appendix 2: Breakdown of the number of articles per study by intervention and health outcome.

Appendix 3: Sub-analysis of birthweight when ICS was deployed in the last trimester. Number of observations = 1828. Abbreviations: MD = mean difference, g= grams, 95% CI = 95% Confidence interval, I^2 = percentage variability of the effect estimates as a result of heterogeneity rather than chance, τ^2 tau-squared, Test of $\theta_i = \theta_j$: Q(2) = chi-squared with degrees of freedom, p = p value, Test of $\theta = 0$: z = z statistic for overall estimate.

Appendix 4: Sub-analysis of LBW when ICS was deployed in the first trimester. Number of observations = 1660. Abbreviations: OR = Odds ratio, 95% CI = 95% Confidence interval, I^2 = percentage variability of the effect estimates as a result of heterogeneity rather than chance, τ^2 tau-squared, Test of $\theta_i=\theta_j$: Q(1) = chi-squared with degrees of freedom, p = p value, Test of $\theta = 0$: z = z statistic for overall estimate.

Appendix 5: Sub-analysis of LBW when ICS was deployed in the third trimester. Number of observations = 1843. Abbreviations: OR = Odds ratio, 95% CI = 95% Confidence interval, I^2 = percentage variability of the effect estimates as a result of heterogeneity rather than chance, τ^2 tau-squared, Test of $\theta_i=\theta_j$: Q(2) = chi-squared with degrees of freedom, p = p value, Test of $\theta = 0$: z = z statistic for overall estimate.

Appendix 6: Type of intervention compliance observed, how it was measured and reported result by intervention type.

Appendix 7: Sub-analysis of birthweight when a reduction in HAP was observed with the intervention (ICS). Number of observations = 835. Abbreviations: MD = mean difference, g= grams, 95% CI = 95% Confidence interval, I^2 = percentage variability of the effect estimates as a result of heterogeneity rather than chance, τ^2 tau-squared, Test of $\theta_i=\theta_j$: Q(1) = chi-squared with degrees of freedom, p = p value, Test of $\theta = 0$: z = z statistic for overall estimate.

Appendix 8: Sub-analysis of LBW when a reduction in HAP was observed with the intervention (ICS). Number of observations = 1525. Abbreviations: OR = Odds ratio, 95% CI = 95% Confidence interval, I^2 = percentage variability of the effect estimates as a result of heterogeneity rather than chance, τ^2 tau-squared, Test of $\theta_i = \theta_j$: Q(1) = chi-squared with degrees of freedom, p = p value, Test of $\theta = 0$: z = z statistic for overall estimate.

Appendix 9: Sub-analysis of ARI when a reduction in HAP was observed with the intervention (ICS). Number of observations = 50192. Abbreviations: RR = Rate Ratio, 95% CI = 95% Confidence interval, I^2 = percentage variability of the effect estimates as a result of heterogeneity rather than chance, τ^2 tau-squared, Test of $\theta_i = \theta_j$: Q(1) = chi-squared with degrees of freedom, p = p value, Test of $\theta = 0$: z = z statistic for overall estimate.

| Article | Rating for Selection bias | Rating for study design | Rating for confounders | Rating for blinding | Rating for Data collection Methods | Rating for withdrawals and dropouts | Global rating |
|------------------------------|------------------------------|----------------------------|------------------------|------------------------|---|---|---------------|
| Adane et al., 2021 | MODERATE | STRONG | MODERATE | MODERATE | MODERATE | STRONG | STRONG |
| Alexander et al., 2017 | MODERATE | STRONG | STRONG | MODERATE | MODERATE | STRONG | STRONG |
| Alexander et al., 2018 | MODERATE | STRONG | STRONG | MODERATE | MODERATE | MODERATE | MODERATE |
| Amhed et al., 2015 | MODERATE | MODERATE | Moderate | WEAK | WEAK | STRONG | WEAK |
| Hanna <i>et al.,</i> 2017 | MODERATE | STRONG | WEAK | MODERATE | WEAK | WEAK | WEAK |
| Harris <i>et al.,</i> 2011 | WEAK | WEAK | WEAK | MODERATE | MODERATE | MODERATE | WEAK |
| Hartinger et al., 2016 | MODERATE | STRONG | STRONG | MODERATE | MODERATE | STRONG | STRONG |
| Katz <i>et al.</i> , 2020 | MODERATE | STRONG | MODERATE | MODERATE | STRONG | STRONG | STRONG |
| Kirby et al., 2019 | MODERATE | STRONG | MODERATE | MODERATE | STRONG | STRONG | STRONG |
| Litchfeild 2018 | STRONG | STRONG | MODERATE | MODERATE | MODERATE | STRONG | STRONG |
| Mortimer et al., 2017 | MODERATE | STRONG | STRONG | STRONG | MODERATE | STRONG | STRONG |
| Schilmaan et al., 2015 | MODERATE | STRONG | MODERATE | WEAK | STRONG | MODERATE | MODERATE |
| Smith et al., 2011 | STRONG | STRONG | MODERATE | STRONG | STRONG | STRONG | STRONG |
| Teilsch et al., 2016 | MODERATE | STRONG | WEAK | MODERATE | STRONG | MODERATE | MODERATE |
| Thompson <i>et al.,</i> 2011 | MODERATE | STRONG | MODERATE | MODERATE | MODERATE | WEAK | MODERATE |
| Wylie 2017 | MODERATE | STRONG | MODERATE | MODERATE | MODERATE | MODERATE | STRONG |

Appendix 10: Breakdown of the results for the six components of the quality and risk of bias assessment.